

Brightness discrimination and contrast sensitivity in chronic glaucoma – a clinical study

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Abstract

The visual acuity, the difference in sensitivity of the two eyes to light (brightness ratio), and contrast sensitivity were assessed in 28 patients with chronic open angle glaucoma and compared with those of 41 normal controls of similar ages and visual acuity. The results obtained were related to the results of Tübingen visual field analysis in patients with glaucoma. Twenty-four of the 28 glaucoma patients (86%) had a significant disparity in brightness ratio between the two eyes. This was found to match the frequency of visual field loss. Moreover, there was a significant relationship between the interocular differences in brightness sense and the difference in the degree of visual field loss between the two eyes. Of the glaucoma patients 39% had sum contrast sensitivities outside the normal range for age-matched normal controls. No significant correlation was found between the interocular difference in brightness sense and the visual acuity or the interocular difference in sum contrast sensitivity. It is concluded that, in the presence of a normal visual acuity, the brightness ratio test warrants evaluation as a potential screening test for chronic open angle glaucoma.

The diagnostic features of primary open angle glaucoma comprise raised intraocular pressure and cupping of the optic disc in association with characteristic visual field defects.¹ Other methods of clinical evaluation include contrast sensitivity^{2,3} and retinal nerve fibre layer photography with red-free light.⁴ It has been suggested that contrast sensitivity, measured by Arden gratings, may provide a sensitive means of evaluating patients with open angle glaucoma.² Subsequent studies have failed to validate this finding.^{5,6} However, with the use of electronic testing systems with a wide range of spatial frequencies abnormalities of contrast sensitivity have been shown.⁷ Photography of the nerve fibre layer of the retina requires considerable skill both to take and to interpret,⁴ which limits the use of this method.

Apparant reduction in the brightness of objects or the intensity of colour is a well recognised feature of optic nerve disease. The difference in the perception of colour brightness between the two eyes is commonly used clinically to evaluate optic nerve function.⁸ A quantitative means of assessing brightness discrimination has been described.⁹ Crossed polarising lenses are placed in front of each eye, and the angle between the pair in front of the better eye is altered until light is perceived as having equal intensity for each eye.¹⁰

The purpose of the present study is to deter-

mine whether the interocular difference in brightness sense is abnormal in patients with primary open angle glaucoma. The results obtained have been analysed with regard to sensitivity and specificity for the detection of glaucoma and compared with those of visual acuity, visual field, and contrast sensitivity.

Materials and methods

PATIENTS AND CONTROLS

Twenty-eight patients with chronic open angle glaucoma were examined. Twenty-four had bilateral glaucoma and four unilateral. Eighteen were male and 10 female. Ages ranged from 31 to 81 years (mean 64 years). All had visual acuities of 6/9 or better except for eight patients with visual acuities between 6/12 and 6/36 due to lens opacities. They all fulfilled two or more of the following criteria for the diagnosis of glaucoma:

(a) An intraocular pressure equal to or greater than 21 mmHg on two or more occasions.

(b) Visual field loss. Nerve fibre bundle defects represent early glaucomatous field loss, and these manifest as circumscribed paracentral defects, nasal steps, arcuate scotomas, and sector shaped defects. Progression of field loss may produce an increase in the density of existing scotomas, new scotomas, and ring scotomas. In advanced glaucomatous field loss, a tunnel vision or a temporal island of vision may be all that is left.

(c) Pathological cupping of the optic disc with characteristic changes at the neuroretinal rim.^{11,12}

Patients who had additional ophthalmic pathology and patients with anisocoria greater than 2 mm were excluded from the study.

Forty-one normal subjects (81 eyes) with ages ranging between 13 and 70 years (mean 38 years) were examined as controls. Twelve were male and 29 female. The visual acuity in all eyes was 6/9 or better. In all cases a detailed medical history was taken.

CLINICAL METHODS

Detailed clinical ophthalmic examination was carried out on all patients and controls. The best corrected visual acuities for near and distance were determined. The pupil diameters were compared in room luminance comparable to the background luminance used for the brightness discrimination test.

A single observer performed central Tübingen visual field assessment on all glaucoma patients using at least two isoptres. Each visual field loss was scored according to the protocol described by Thompson and colleagues¹³ but modified by

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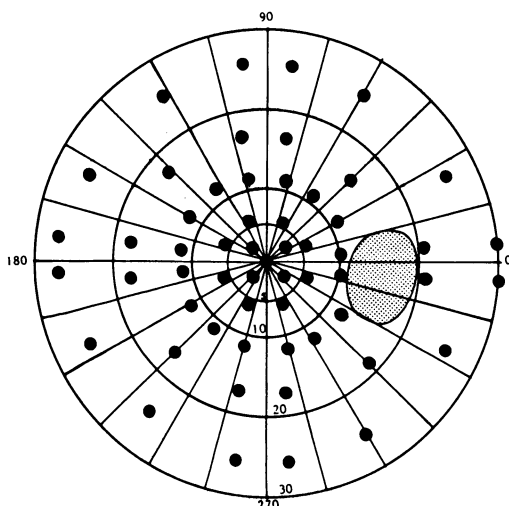


Figure 1: Visual field score. This is a diagram of the central Tübingen field chart. Each visual field defect was scored according to a protocol modified from that of Thompson et al¹³ where solid points were marked at regular intervals within the central 30° of visual field. Any solid point falling within areas of relative scotoma, with 10 apostilb target, was given a score of 0.5, and any point within areas of scotoma to 0.5 apostilb target was given a score of 1. For points falling within areas of absolute scotoma a score of 2 was given to each point.

giving extra weighting to the score according to the density of the scotoma (Fig 1). Figure 1 is a diagram of the central Tübingen field chart where solid points are marked at regular intervals. Any solid point falling within areas of relative scotoma, with 10 apostilb target, was given a score of 0.5, and any point within areas of scotoma to 0.5 apostilb target was given a score of 1. For solid points falling within areas of absolute scotoma a score of 2 was given to each point. The visual field loss was then scored by adding all the scores of all points present on or within all scotomata in the visual field. Therefore visual field loss had a score range of 0 (no scotoma) to 114 (absolute scotoma in the whole central 30° of field).

The brightness comparison test was carried out with a standard trial frame with a pair of polarising lenses on each side.⁹ The rear lens was fixed and the front lens was rotated to alter the amount of light transmitted. (A calibration curve giving the percentage of light transmitted as a function of angular difference between polarisers had been determined in an initial experiment.) Each subject was seated at 1 metre from an x ray viewing box which emitted a homogeneous white light with a luminance of 640 lumina m⁻². The box subtended 70° of visual field horizontally and 40° vertically. The lenses were first set for maximum light transmission. Each eye was alternatively covered and the subject asked to comment on any disparity in brightness between the two eyes. The front polarising lens of the 'better eye' was then rotated to decrease the amount of light transmitted till its brightness appeared equal to that in the 'worse eye,' in which light was 100% transmitted. (The pair of polarising lenses are parallel to each other, allowing 100% light transmission.) The test was repeated three times and the mean value of the polariser position determined. By means of the polariser calibration curve the ratio of light intensities transmitted to each eye was calculated

as a percentage to give the brightness sense ratio. For example, if the better eye required only 60% of light transmitted for it to perceive equal brightness to the worse eye (which has 100% light transmission), then the brightness sense ratio is 60% – that is, the luminance perceived in the worse eye is only 60% of that in the better eye.

Spatial contrast sensitivity was determined by the Nicolet Optronics CS 2000 apparatus (Nicolet Biomedical Instruments). This system comprises a display monitor, a control console with keyboard, and an observer response box. It executes a standard von Bekesy tracking test of contrast sensitivity, whereby a number of electronically generated vertical sinusoidal grating patterns are displayed on a television screen. Each subject was seated at 3 metres giving a field size of 5°×4° for the television screen. The room luminance was comparable to the screen luminance. Each eye was tested in turn with the appropriate distance refractive correction when required. Pupil size was recorded but not altered. To minimise the ambiguity of this psychophysical test, the method of examination, the instructions given, and the patients' criteria of visible contrast were precisely standardised. In this study the machine was programmed to project sinusoidal gratings starting from low to high spatial frequencies. In anticipation of those test gratings the patients' contrast sensitivity may be higher than it would have been if the gratings were randomly displayed. However, since the same instructions and criteria of contrast perception were used, this would not affect the overall results and its interpretation. Six spatial frequencies were tested (0.5, 1, 3, 6, 11.4, and 22.8 cycles/degree), and the logarithm of contrast threshold for each frequency was computed. The modulation transfer function was determined in every case by plotting the logarithm of contrast threshold against spatial frequency.

Results

Most of the control subjects had no significant ophthalmological history or findings except for two who had received antituberculosis therapy 20 years earlier and one who had had bilateral central serous retinopathy eight years before. Eight control subjects smoked more than 20 cigarettes a day. For none of these exceptions did the results obtained for the contrast sensitivity and brightness sense evaluation fall outside one standard deviation from the mean. One subject had unilateral cataract. The affected eye was not used in the study, which naturally precluded the use of this subject for interocular comparisons.

VISUAL FIELDS

The possible score for visual field loss for each eye ranged from 0 to 114. No visual field loss was detected in any of the eyes of the control subjects. Among the patients with glaucoma a visual field score of more than 10 was found in 26 out of 28 patients (93%) (in 44 out of 52 glaucomatous eyes – 85%). The difference in the visual field scores between the two eyes was

TABLE I Brightness sense score in normal subjects

Age range (years)	Number of subjects	Brightness sense score (%)			
		Mean	SD	95% Confidence limit*	99% Confidence limit†
11–20	7	93.00	2.08	89.6	88.2
21–30	8	96.75	1.04	95.0	94.3
31–40	10	95.40	1.84	92.4	91.1
41–50	5	96.80	1.10	95.0	94.2
51–60	6	92.83	2.71	88.4	86.5
61–70	4	94.75	4.27	87.7	84.8
All	40	94.98	2.58	90.7	89.0

*95% Confidence limit given by mean – 1.65 SD.
 †99% Confidence limit given by mean – 2.33 SD.

determined. Twenty-one of the 28 patients (75%) showed differences in visual field score greater than 5.

BRIGHTNESS SENSE COMPARISON TEST

Table I details the brightness sense scores for the control subjects separated by age group. For all ages a brightness sense score of 89% corresponds to the 99 percentile limit. Analysis of variance confirmed that there were significant differences between age groups. Younger and older subjects gave lower brightness sense ratios corresponding to greater interocular differences, and the results of individuals in these age groups varied more widely. Subjects between 20 and 50 years of age provided higher scores with less variation.

Compared with the 99% confidence limit for age-matched controls, 24 of 28 glaucoma patients (86%) had abnormal ratios. In all these patients, the worse eye had a lower brightness perception. Two patients showed a 2 mm difference in pupil diameter at the time of examination, while the remainder had equal pupils. This may have affected their brightness sense to an indeterminate degree. However, if these two patients are removed from the group, the percentage of patients returning scores outside the 99% normal limit remains unchanged.

CONTRAST SENSITIVITY

Table II illustrates the contrast sensitivity results for normal subjects. Where both eyes of patients were tested, the average of the sensitivities of the two eyes was taken for further analysis to deal

TABLE II Contrast threshold for normal subjects. For each spatial frequency the mean contrast threshold is given with the standard deviation below in brackets. The column headed 'sum' relates to the sum of thresholds for the 6 gratings

Age range (years)	Number of subjects	Mean contrast threshold for various spatial frequencies*						
		0.5	1	3	6	11.4	22.8	Sum
10–19	6	1.16 (0.12)	1.79 (0.06)	2.18 (0.05)	2.17 (0.18)	1.91 (0.17)	1.26 (0.40)	10.5 (0.7)
20–29	9	1.21 (0.12)	1.97 (0.21)	2.35 (0.19)	2.27 (0.25)	2.01 (0.28)	1.63 (0.23)	11.4 (0.9)
30–39	10	1.26 (0.15)	1.94 (0.20)	2.34 (0.20)	2.29 (0.17)	1.99 (0.22)	1.35 (0.29)	11.2 (0.8)
40–49	5	1.14 (0.16)	1.87 (0.09)	2.35 (0.26)	2.24 (0.45)	1.77 (0.57)	1.43 (0.64)	10.8 (2.0)
50–59	6	1.14 (0.28)	1.90 (0.25)	2.18 (0.21)	2.34 (0.19)	1.94 (0.38)	1.19 (0.63)	10.7 (1.7)
60+	5	1.23 (0.04)	1.75 (0.15)	1.94 (0.24)	1.81 (0.24)	1.40 (0.27)	0.64 (0.54)	8.8 (1.0)
All	41	1.20 (0.16)	1.89 (0.19)	2.25 (0.23)	2.22 (0.28)	1.88 (0.35)	1.30 (0.50)	10.7 (1.4)

*All contrast thresholds in this table are in logarithmic scales and are negative values. For simplicity the minus sign is not shown. Therefore the larger the value the greater is the contrast sensitivity.

TABLE III Abnormal contrast sensitivities in 52 eyes with chronic glaucoma. Results are classified abnormal if outside the 95% limit for the corresponding age group of control subjects

Gratings (cycles/degree)	No abnormal	% Abnormal
0.5	8	15.4
1.0	7	13.5
3.0	8	15.4
6.0	11	21.2
11.4	9	17.3
22.8	1	1.9
Sum of contrast sensitivities	13	25.0

with the possible correlation between values for pairs of eyes.¹⁴

Analysis of variance revealed that all groups of patients up to 60 years of age were closely similar but that there was a significant drop in contrast sensitivity for those over 60 years ($p < 0.001$). When the sensitivities for individual gratings were analysed, the over 60 years age group was found to have significantly poorer contrast sensitivity than younger subjects at spatial frequencies of 3 cycles/degree and higher ($p < 0.01$ for each grating). At the lower spatial frequencies employed, 0.5 and 1 cycle/degree, all age groups performed similarly.

The interocular ratios of sum contrast sensitivity were also calculated for normal controls. Expressing all values as a figure greater than 1 gave a mean of 1.09 and standard deviation of 0.06, with a 95 percentile limit of 1.19 (mean + 1.65 SD). Analysis of variance showed no significant differences of interocular ratio among the various age groups ($0.05 < p < 0.1$).

Table III shows the number of abnormal contrast sensitivities for the spatial frequencies tested and for sum contrast sensitivity for the 52 eyes with chronic glaucoma. The low and medium spatial frequencies were more commonly disturbed, while the higher frequencies were relatively spared. This would be expected, as high spatial frequencies correspond more closely to visual acuity. In total, 39% of glaucoma patients gave sum contrast sensitivity values below the normal limit (mean – 1.65 SD) for their age group. When the interocular ratios of the sum contrast thresholds are considered, 12 of the 28 patients (43%) had ratios outside the normal range.

COMPARISONS OF DIFFERENT TESTS

An attempt was made to correlate brightness ratio with three other interocular measures – the visual acuity difference, the interocular ratio of sum contrast sensitivity, and the visual field score difference. For these comparisons Snellen acuities were transformed by the method of Westheimer, where the visual acuity was represented by the value of $\log(1/\text{Snellen fraction})$.¹⁵ Pearson correlation coefficients indicated no significant correlation between brightness ratio and either visual acuity difference or sum contrast sensitivity ratio ($p > 0.1$ in both cases), but there was a significant correlation with visual field difference ($0.02 < p < 0.05$) (Fig 2). Note that in all cases the direction of any observed difference was always that the poorer eye in the

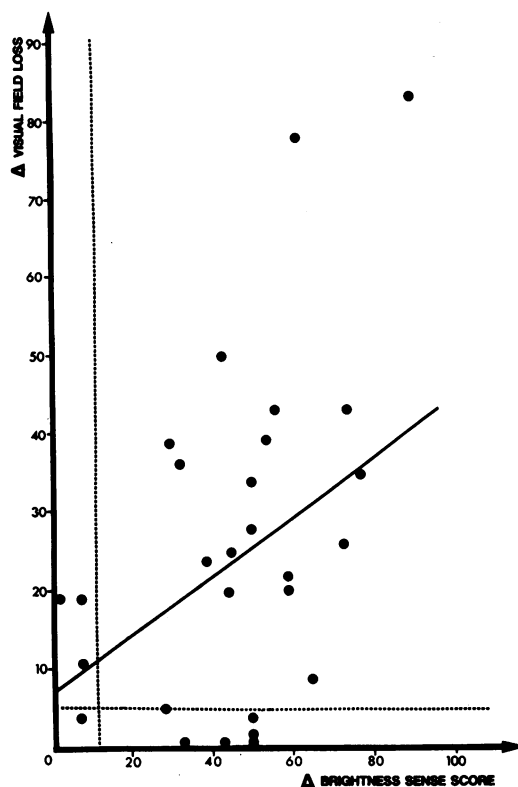


Figure 2: Interoocular difference in visual field loss versus interocular difference in brightness sense score for 28 glaucoma patients. The solid line was obtained by linear regression analysis. The dotted lines mark the normal limits (99%) of brightness score and interocular field difference.

brightness discrimination test (that is, the one with 'dimmer' vision) was also poorer in terms of the other measures of visual function.

As can be seen in Fig 2, six patients outside the normal range of brightness ratio had no significant visual field score differences. Conversely, only three patients who had abnormal interocular visual field differences showed no abnormalities in significant brightness sense. However, as regards the presence of any glaucomatous field loss, three patients who had fairly similar field loss passed their brightness discrimination test. In contrast there were three other patients, with no significant field defects but with raised intraocular pressures and glaucomatous cupping, who gave abnormal brightness sense ratios.

Discussion

The results of the present study indicate that, while 86% of glaucoma patients had abnormal brightness sense ratios, only 75% showed an interocular difference in visual field score. The sensitivity of the brightness sense comparison test comes very close to the presence of visual field loss in 93% of these patients. The high percentage of visual field loss was biased, as it was one of the criteria for patient selection and indeed for the diagnosis of glaucoma. The sum contrast sensitivity scores, however, were abnormal in only 39% of cases.

The brightness sense ratio test detects only a difference in the perception of brightness between the two eyes. Symmetrical impairment of optic nerve function in both eyes would not result in an abnormal brightness sense test. The

results therefore reflect the asymmetric nature of optic nerve damage in glaucoma.

In a previous study of brightness sense in a variety of ophthalmic conditions,¹⁰ 29 control subjects were assessed, but age variation was not examined. In the present study we have demonstrated significant variations of brightness ratio with age which is pertinent to future investigations. The control subjects aged between 20 and 50 years gave more reproducible responses than the older or younger subjects. Although brightness sense is severely impaired in optic nerve disease and is affected to a greater degree than visual acuity or other visual functions,¹⁰ it is not specific to any particular optic nerve dysfunction.

A difference in pupillary size between eyes would be expected to produce a disparity in the perception of brightness due to differing degrees of retinal illumination. Ideally a correction factor for this should be calculated, but the large number of variables precludes the accurate estimation of such a factor.

There was a significant correlation between the interocular differences in brightness sense and the interocular differences in visual field loss within the central 30° of field. Clinical perimetry and the perception of brightness both depend on retinal sensitivity to light. This positive correlation indicates that the perception of brightness is probably an overall retinal function, with a greater influence being provided by the central 30° of retina.

A significant reduction in contrast sensitivity at medium to high spatial frequencies in elderly normal subjects was found. Similar findings have been reported previously.^{5,16-18} This change in modulation transfer function is probably related to the loss of neuronal cells, either in the retina or along the visual pathway to the visual cortex. On the other hand the interocular ratio of sum contrast sensitivity did not show any marked variation with age, suggesting that loss of contrast discrimination tends to be symmetrical.

Only 39% of patients with glaucoma had abnormal contrast sensitivity, with a generalised depression at all spatial frequencies except the highest. This finding is in keeping with the presence of paracentral visual field loss and the late preservation of central visual acuity in glaucoma. In addition the present study indicates that 45% of glaucoma patients had abnormal interocular sum contrast sensitivity ratios. This ratio is therefore more sensitive as a means of detecting abnormality than the determination of sum contrast sensitivity for each eye, though still less sensitive than either brightness sense or visual field.

Most screening programmes for glaucoma involve measuring the intraocular pressure, recording the visual field, and assessing the optic disc.¹ Other screening tests which have been advocated include oculokinetic visual field assessment,¹⁹ measurement of contrast sensitivity,^{2,3} and nerve fibre bundle assessment with red-free filters.⁴ However, the problems of high cost and complexity of multiple tests have militated against the development of screening programmes for glaucoma. As has been shown in this study, there were a few patients who were missed on the brightness discrimination test but

had visual field defects and vice versa. It would appear that in the presence of a normal visual acuity (which would exclude most other causes of optic nerve dysfunction) an abnormal brightness sense test may prove to be a sensitive means of screening for glaucoma. The test is quick and easy to perform and does not require expensive equipment or technical skill. In addition the results are reproducible, as the patients give consistent results on repeated testing. Together with its sensitivity and low false positive rate it is potentially useful in mass glaucoma screening programmes, especially in the third world countries where trained personnel and financial assistance are limited. Compared to visual field screening, a sensitive and specific test in the diagnosis of glaucoma but which is time consuming and requires trained workers, this test may prove to be more practical.

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